Parasitic black holes
the swallowing of a fuzzy dark matter soliton

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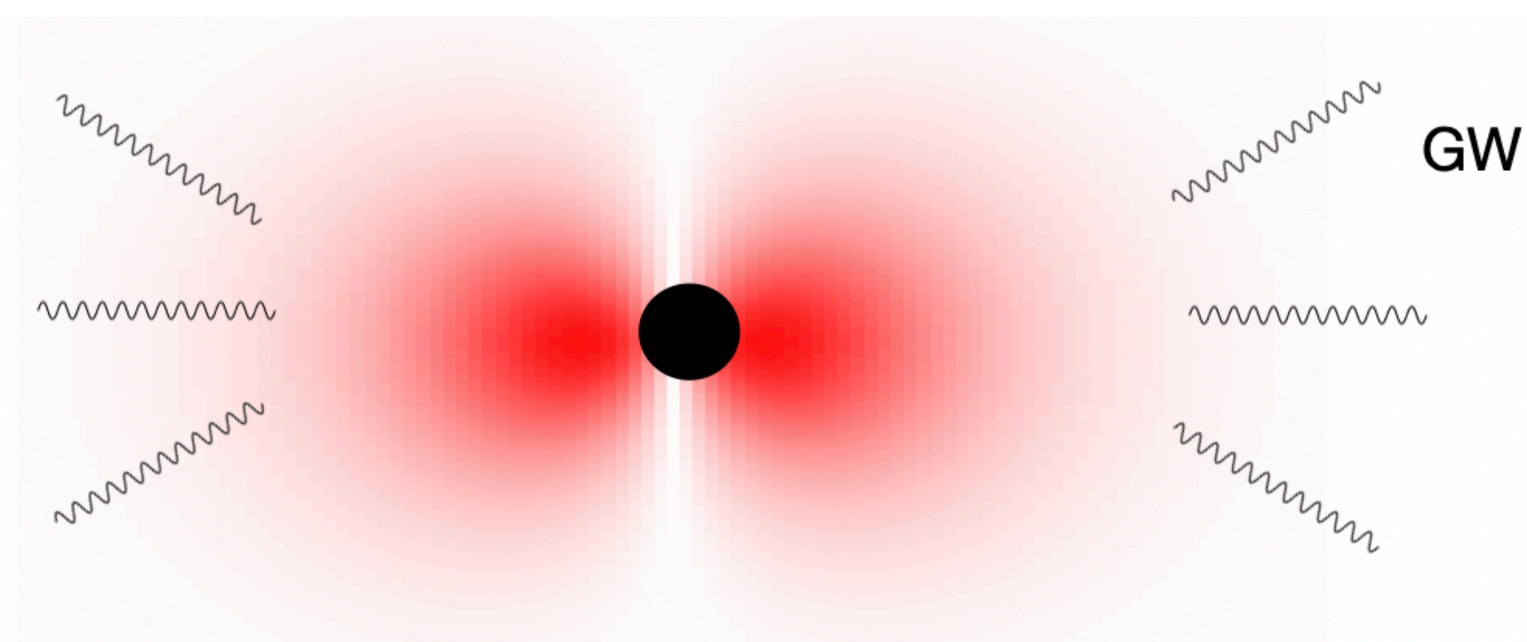
New particles and black hole

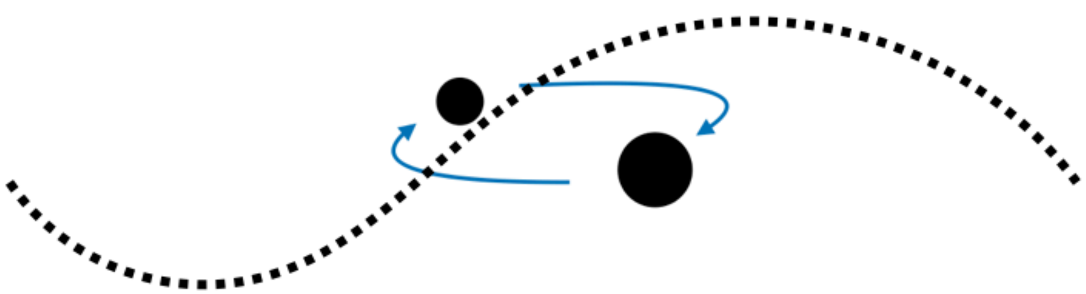
- Mystery of our Universe
  - Dark matter ?? Dark energy ?? *Zwicky (1933) ,Perlmuter et al (1998)….*
  - Quantum theory of gravity ??
- New particles ?
  - axion, axion like particle *Peccei and Quinn (1977) ,Arvataniki et al (2015)….*
  - light vector field, light tensor field *de Rham et al (2011), Hassan et al (2011) ….*
- Superradiant instability → BH is a particle detector !!

$$\tau \sim 100\tilde{a}\left(\frac{10^6 M_\odot}{M}\right)^8\left(\frac{10^{-16}\mathrm{eV}}{\mu}\right)^9 \mathrm{sec}$$

Detweiler (1980) ,Brito et al (2015)….

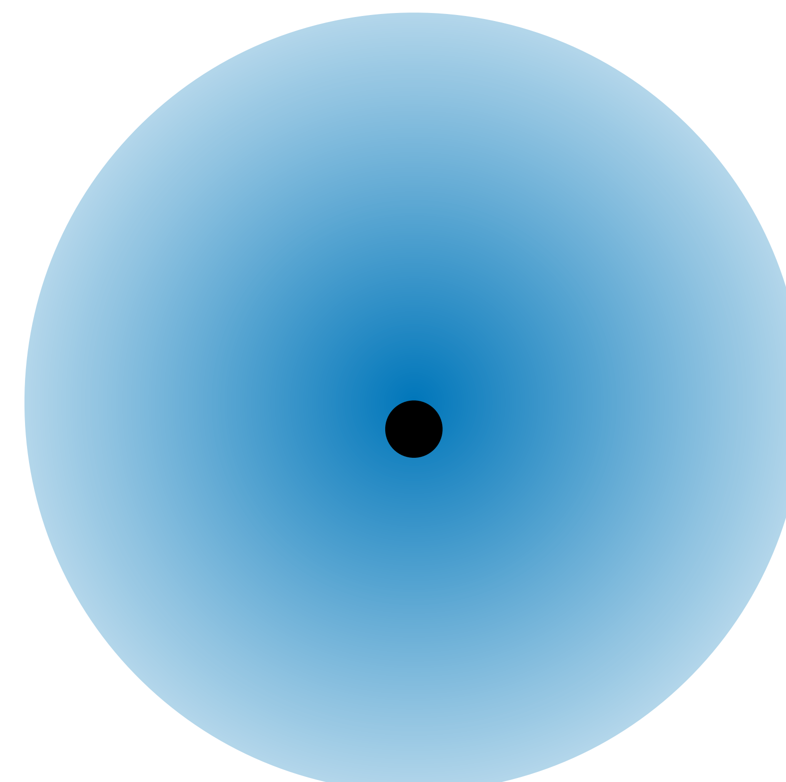


BH as a particle detectors



Binary black hole in light fields

T.I, L.Bernard, V.Cardoso, M.Zilhao (2021)
talk by J. Bamber



Black hole in dark matter halo

Boson star as dark matter

- Fuzzy dark matter scenario *W.Hu et.at.(2000).....*

$$S = \int d^4x\sqrt{-g}\left(\frac{R}{16\pi} - g^{\mu\nu}\nabla_\mu\psi\nabla_\nu\psi^* - \mu^2|\psi|^2\right)$$

$$\frac{M_{\rm BS}}{M_\odot} = 9\times 10^9\frac{100{\rm pc}}{R_{\rm BS}}\left(\frac{10^{-22}\ {\rm eV}}{\mu}\right)^2$$

BS appears at the center of DM halo.

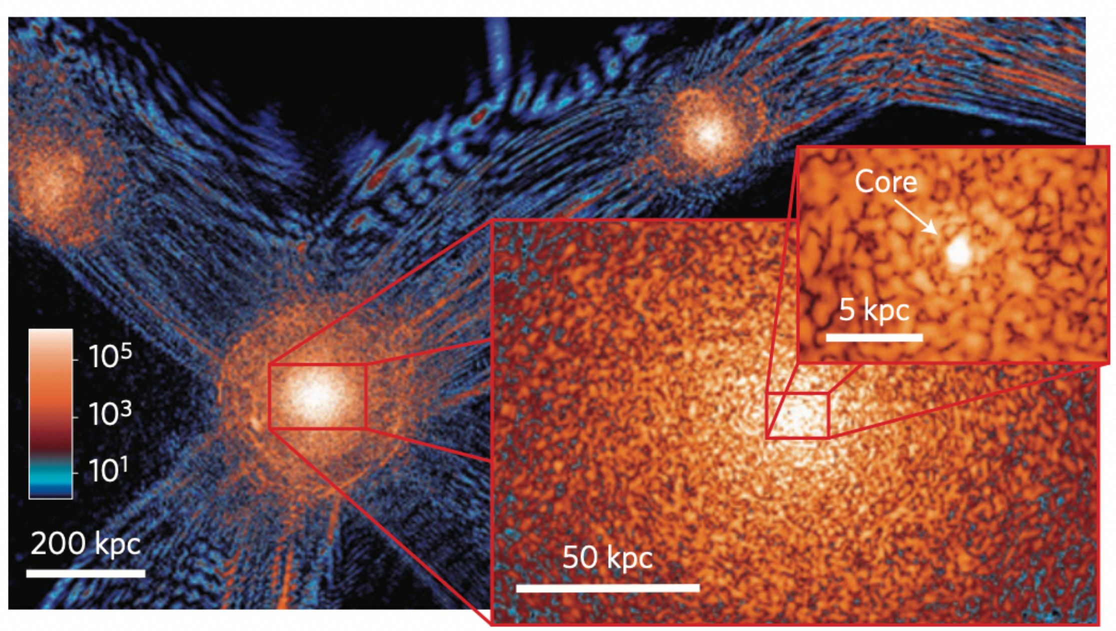


Figure 2 | A slice of the density field of the ψDM simulation on various scales at $z = 0.1$. This scaled sequence (each of thickness 60 pc) shows how quantum interference patterns can be clearly seen everywhere from

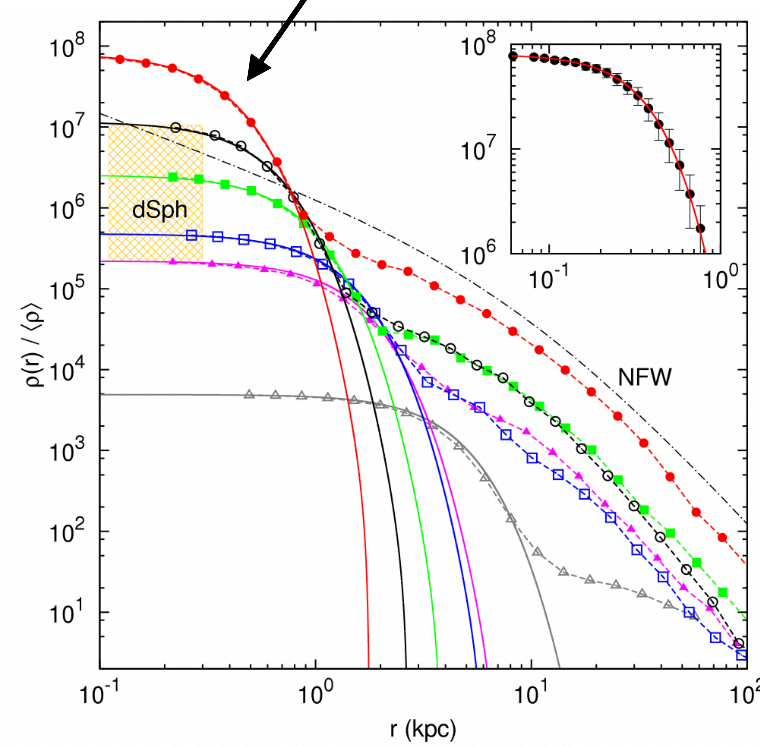
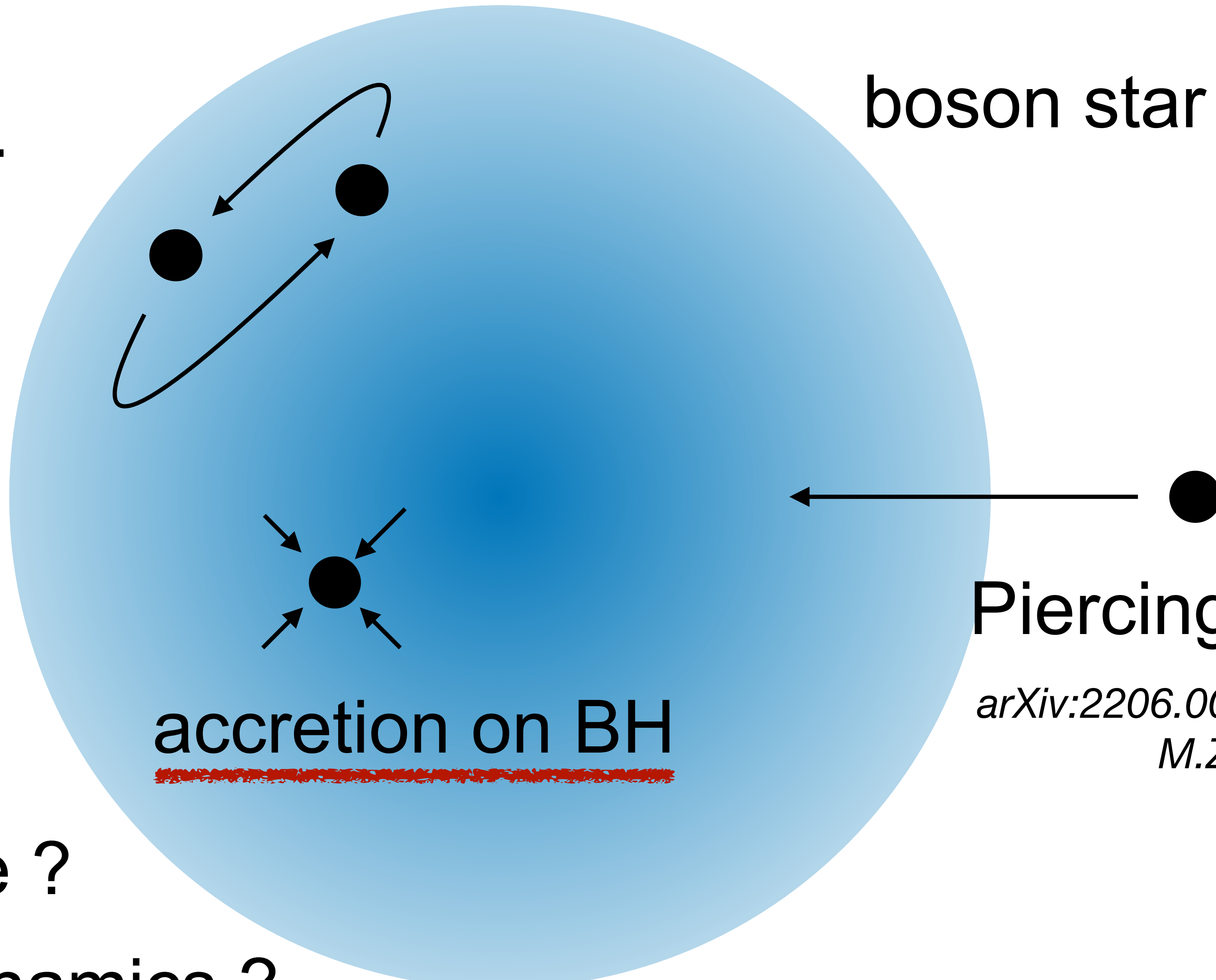


Figure 3: Radial density profiles of haloes formed in the ψDM model. Dashed lines with various sym-

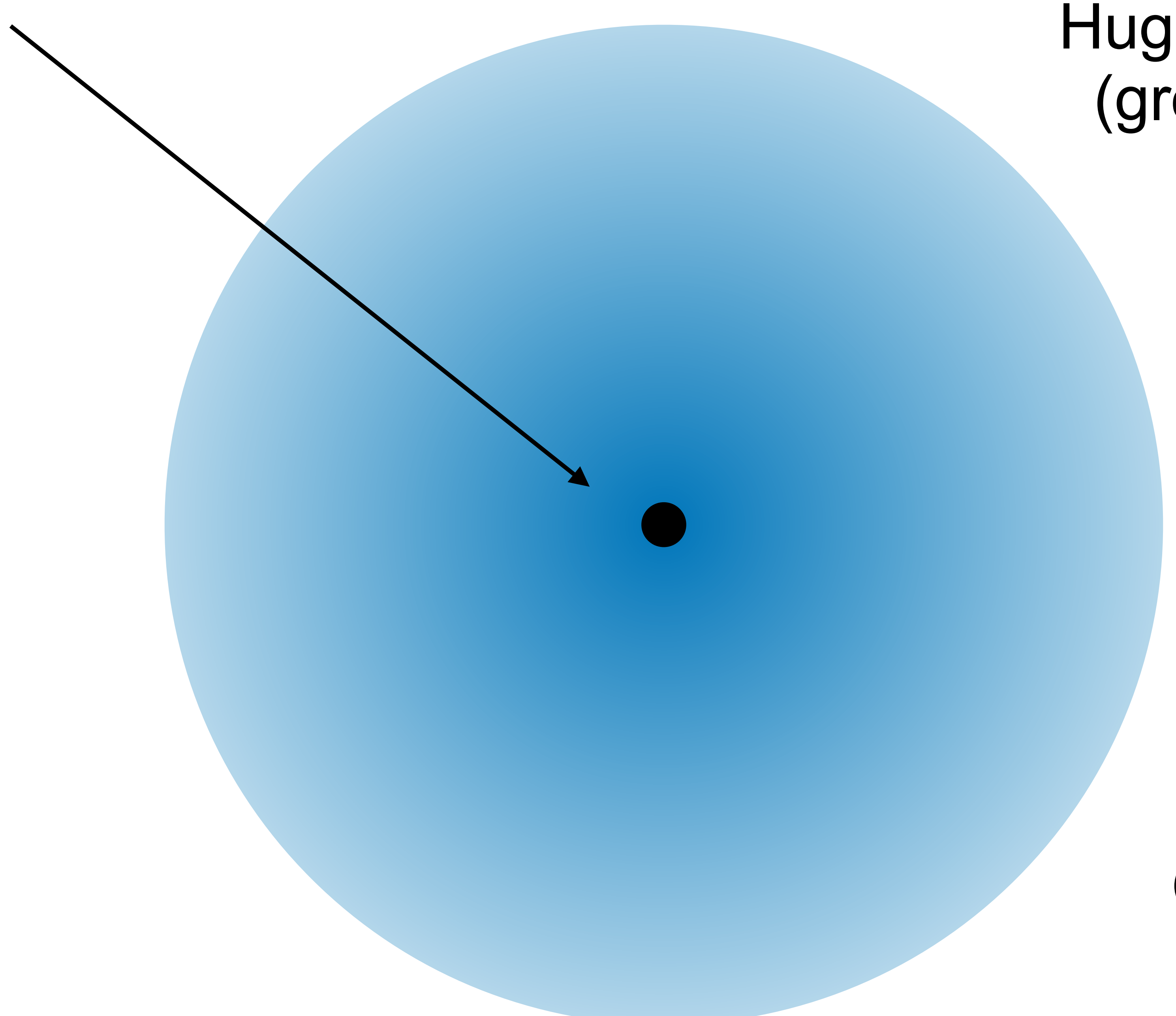
Schive et.at.(2014)

Possible interactions with BHs



- Time scale ?
- Typical dynamics ?

Set up


Black hole (M_0)
Huge boson star
(ground state)
Parameters
$(M_{\rm BS}/M_0, R_{\rm BS}/M_0)$
Initial Data

Relevant physics

- Boson star normal mode *Annulli et al (2020)*

$$\omega_{\rm NM} = \kappa M_{\rm NBS}^2 \mu^3 \sim 0.2{\rm Myr}^{-1}\left(\frac{\mu}{10^{-22}{\rm eV}}\right)^2\left(\frac{M_{\rm BS}}{10^9 M_\odot}\right)^2$$

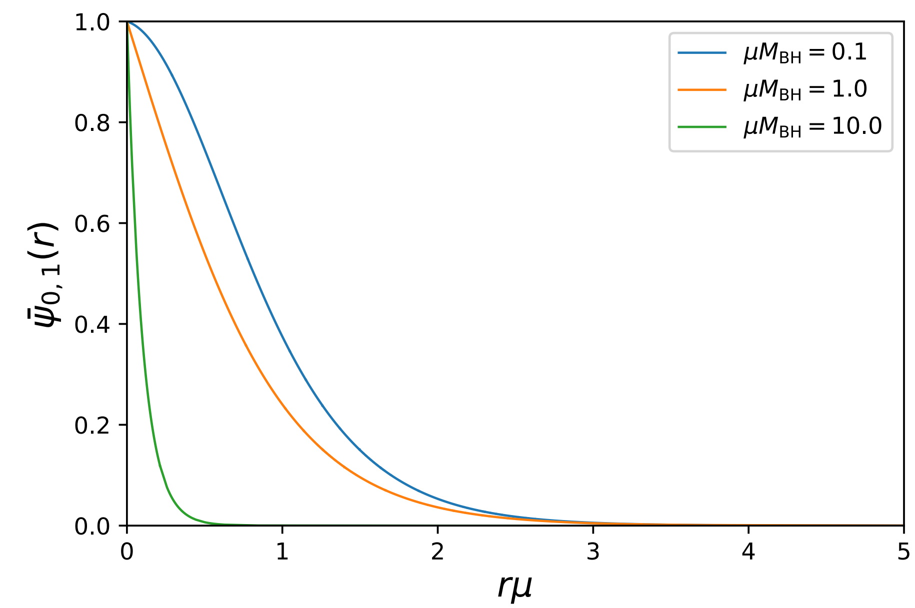
- Schrodinger-Possion eq.

$$\begin{cases} i\dfrac{\partial \Psi}{\partial t} = -\dfrac{1}{2\mu}\Delta\Psi + \mu\Phi_N\Psi \\ \Delta\Phi_N = 4\pi\mu\,|\,\Psi\,|^2 \end{cases}$$

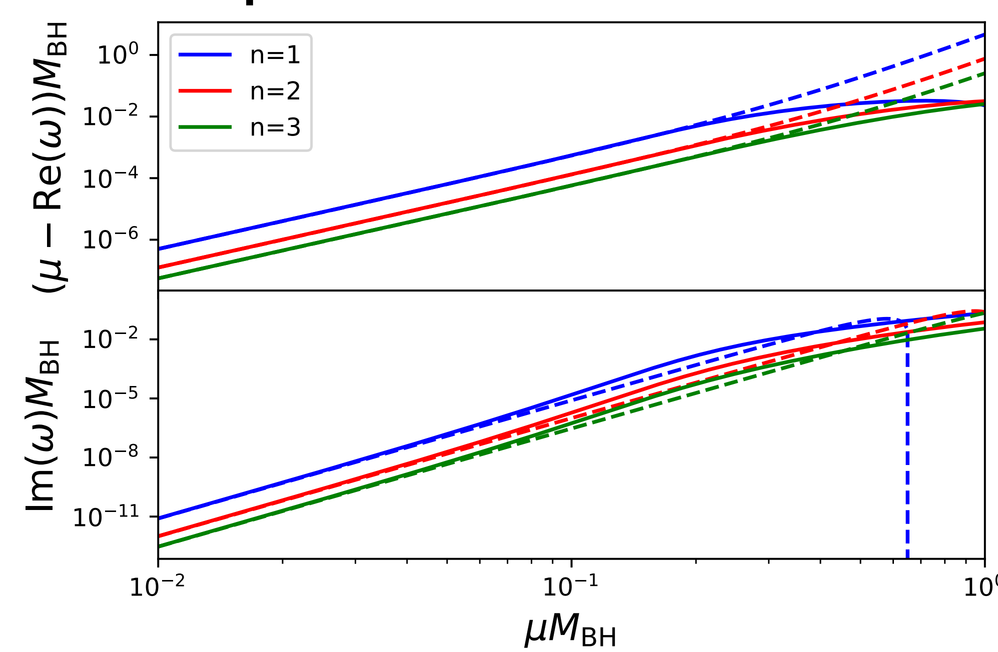
with $\Phi_N = -\dfrac{M_0}{r} + \delta\Phi_N$

- Gravitational atom
  - Bound state of test massive field around BH

Dirty boson star

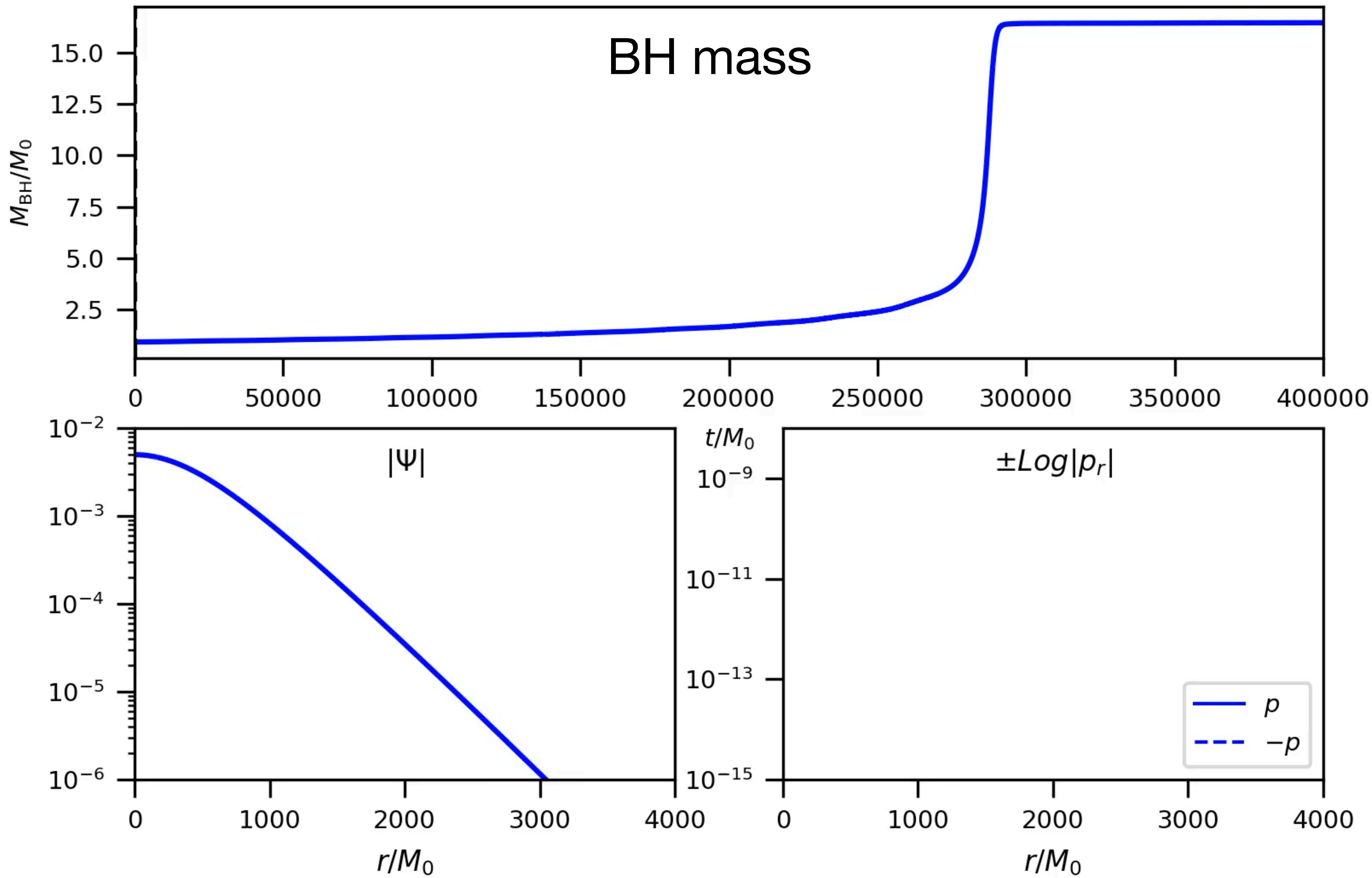


Spectrum of G-atom



Numerical result

$$R_{\rm BS} = 1360 M_{\rm BH,0}$$
$$M_{\rm BS} = 15.5 M_{\rm BH,0}$$



Scalar field

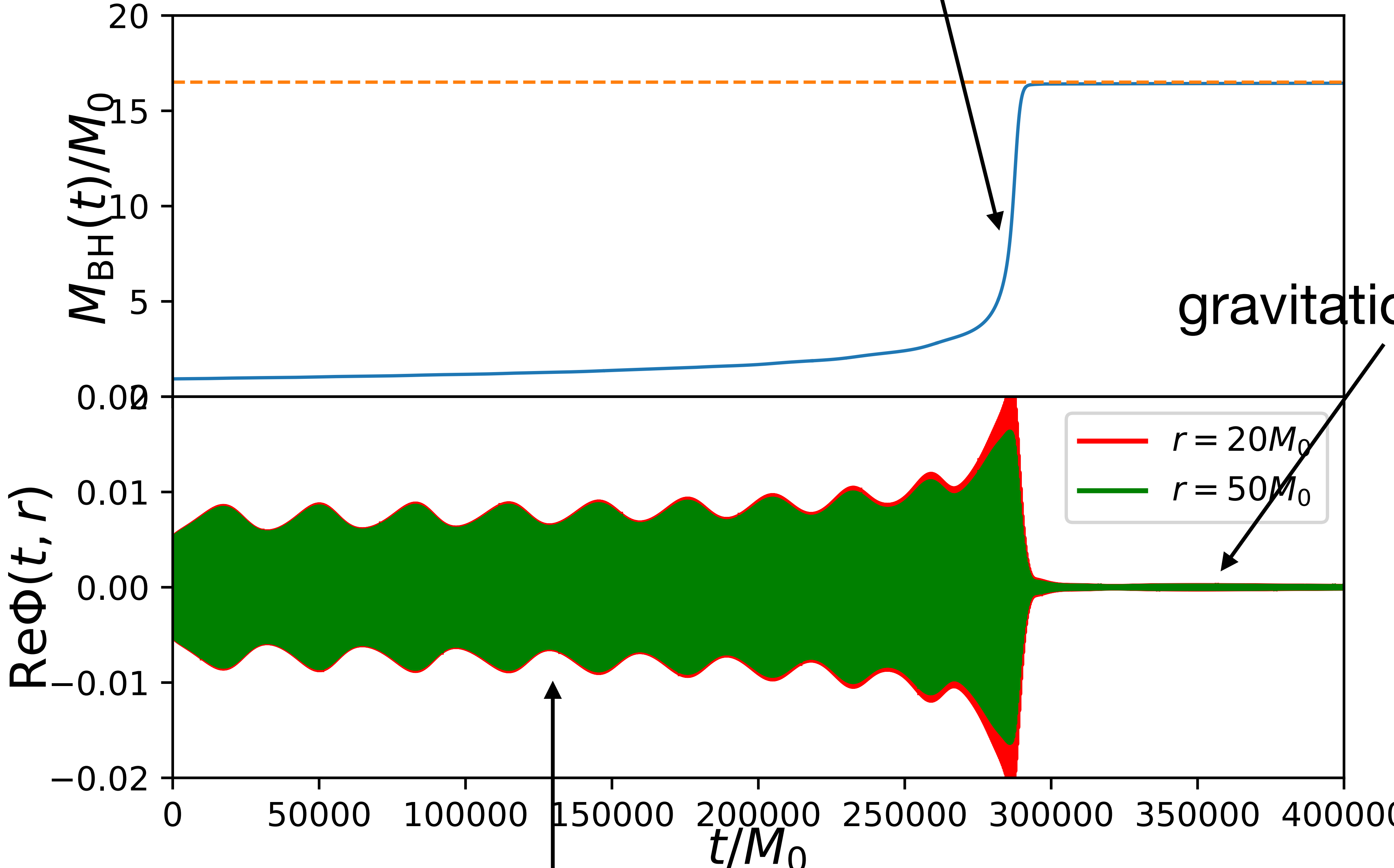
Energy flux

Numerical result

Potential barrier vanishes for large BH.

$M_{\rm BH,crit} = 0.25\mu^{-1}$

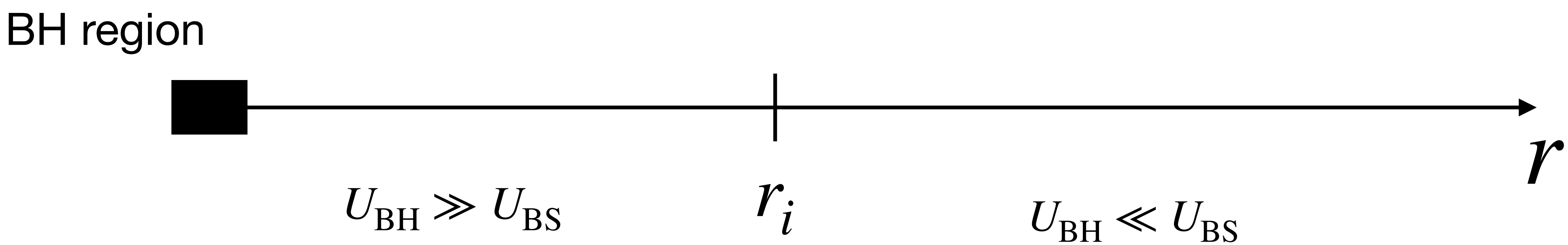
catastrophic stage



gravitational atom

BS normal mode (boson-quake)

Toy model for first phase



- Test field approximation

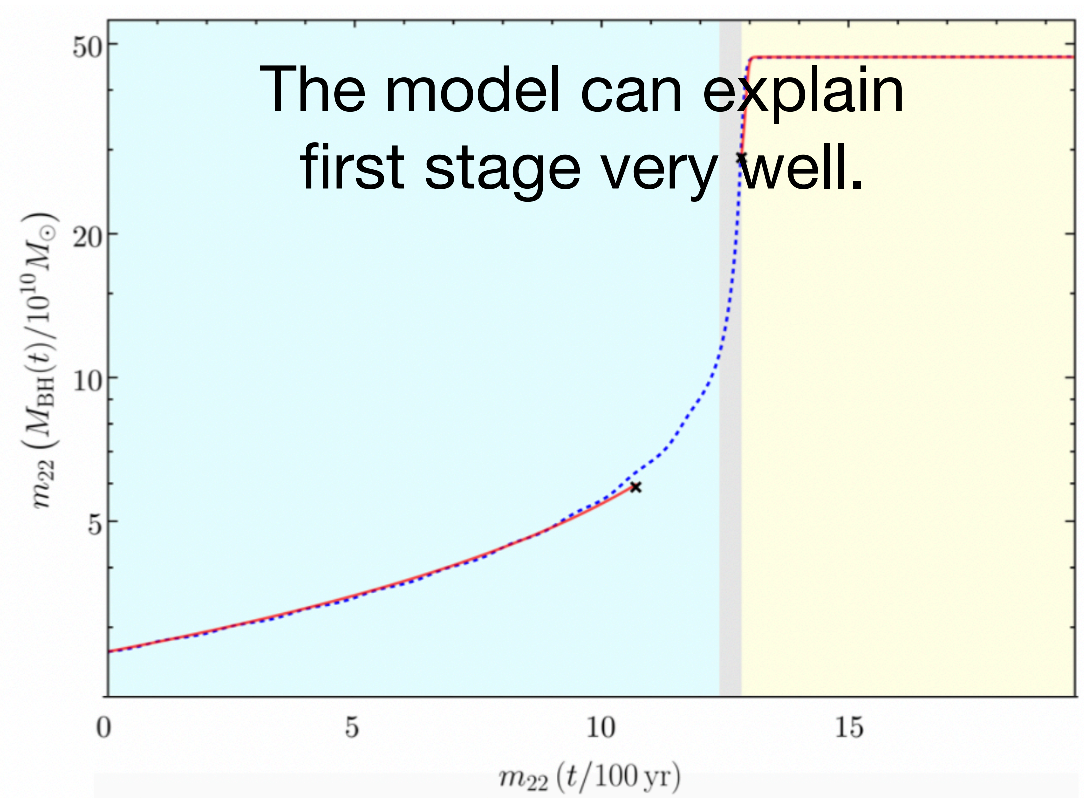
$$\psi \sim \frac{T}{2M} e^{-i\omega\left\{t + 2M\log\left(1 - \frac{r}{2M}\right)\right\}}$$

- matching at $r \sim r_i$
- the energy flux into BH horizon

$$\frac{dM}{dt} \simeq 8\pi \times 10^{-2} (\mu M)^2 (\mu M_{\rm BS})^4 \left(1 + \frac{6M}{M_{\rm BS}}\right)$$

- Schrodinger-Poisson eq.

➡ Dirty boson star

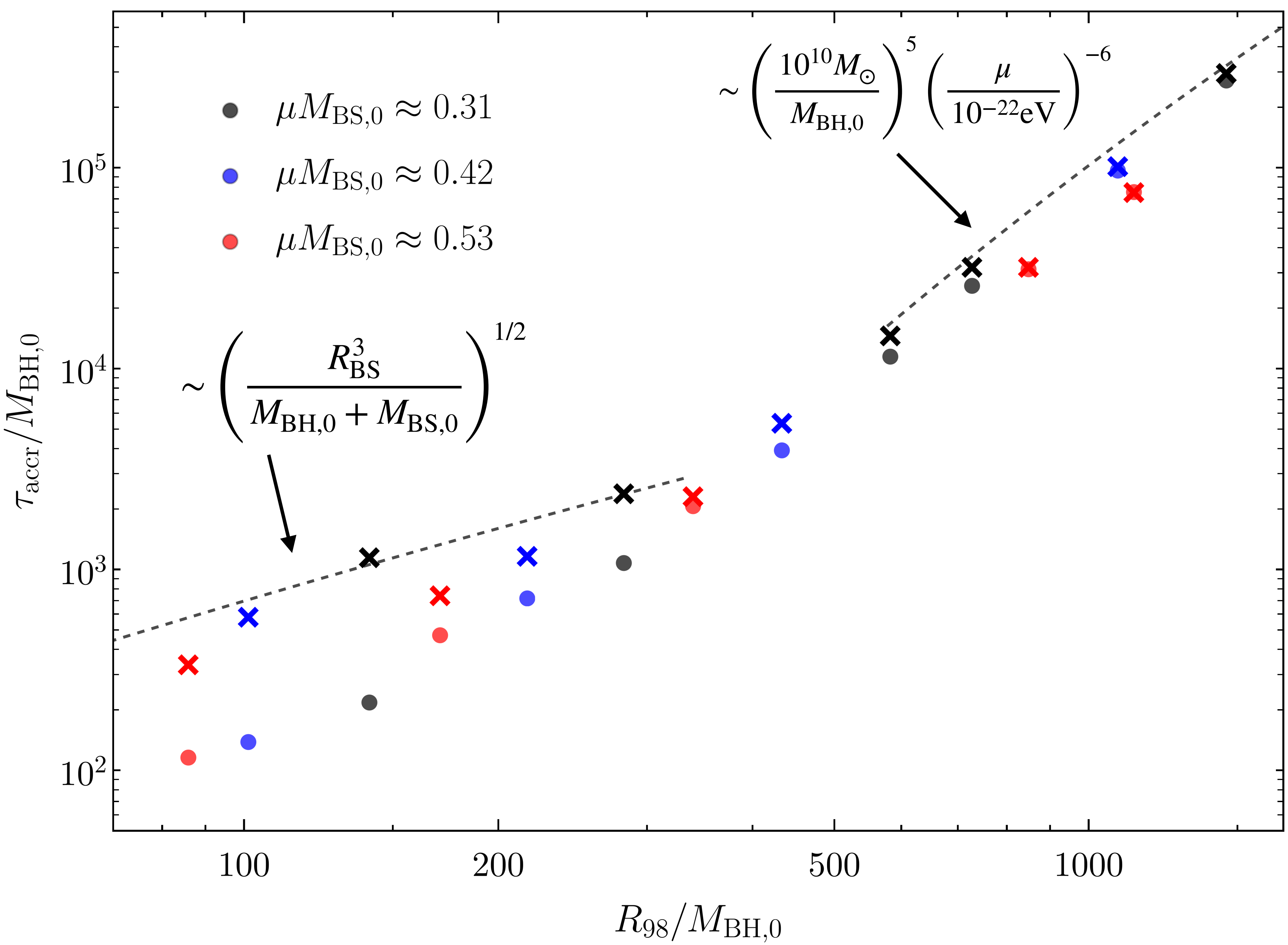


Numerical result

x : t at $M_{\rm BS}(t) = 0.1 M_{\rm BS}(0)$

● : t at $M_{\rm BS}(t) = 0.9 M_{\rm BS}(0)$

Time scale of first phase



Astrophysical applications

- Life time of boson star

$$\frac{\tau_{10\%}}{10\ \mathrm{Gyr}} \sim \mathcal{O}(1)\left(\frac{10^{10}M_\odot}{M_{\mathrm{BH},0}}\right)^5\left(\frac{\mu}{10^{-22}\mathrm{eV}}\right)^{-6}$$

- Soliton-halo relation *Schive et.at.(2014))*

$$M_{\mathrm{BS}} \simeq 6.5\times 10^9 M_\odot\left(\frac{\mu}{10^{-22}\ \mathrm{eV}}\right)^{-1}\left(\frac{M_{\mathrm{halo}}}{10^{14}M_\odot}\right)^{1/3}$$

- BS life time must be longer than Hubble time

$$\tau_{10\%} > \tau_{\mathrm{age}}$$

$$\Rightarrow \quad \mu \lesssim 8\times 10^{-20}\mathrm{eV} \quad \text{with} \quad M_{\mathrm{halo}} \lesssim 10^{15}M_\odot$$

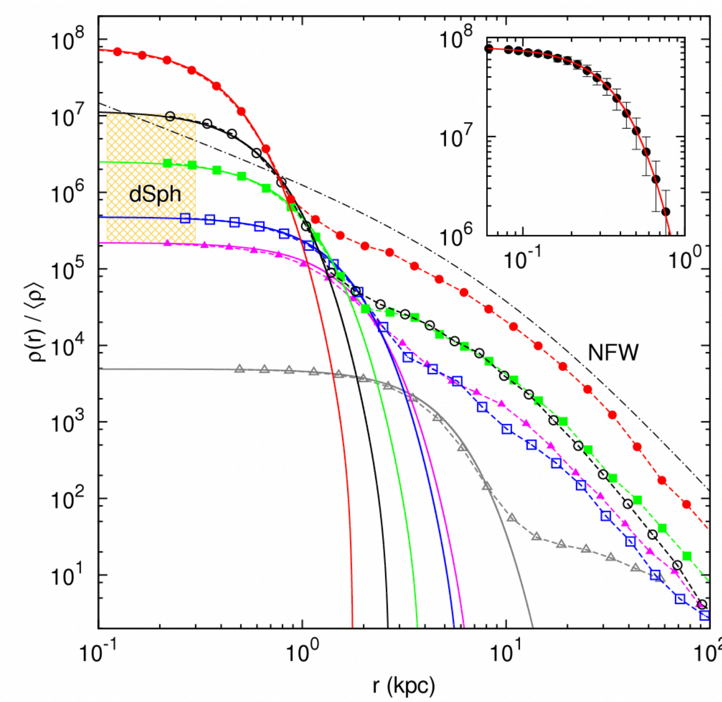
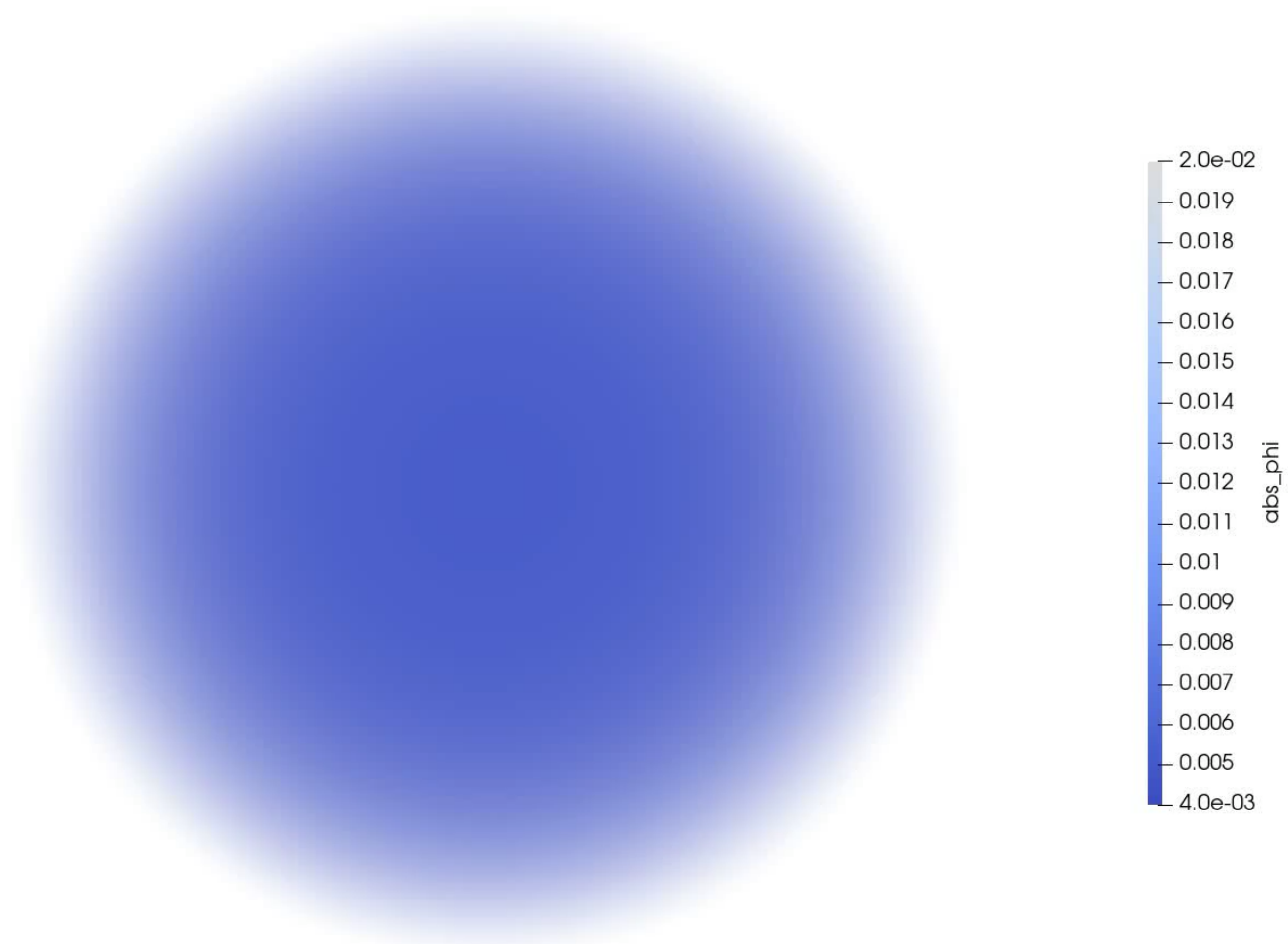


Figure 3: Radial density profiles of haloes formed in the ψDM model. Dashed lines with various sym-

t= 0.00e+00M_0

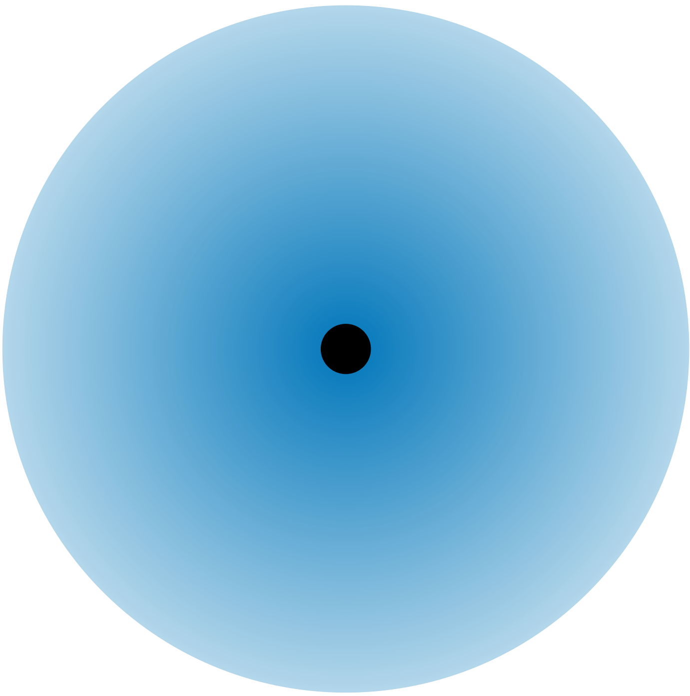

2.0e-02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
0.006
0.005
4.0e-03
abs_phi

t= 3.04e+05M_0


2.5e-04
0.00024
0.00022
0.0002
0.00018
0.00016
0.00014
0.00012
0.0001
8e-5
6e-5
4.0e-05
abs_phi

Summary

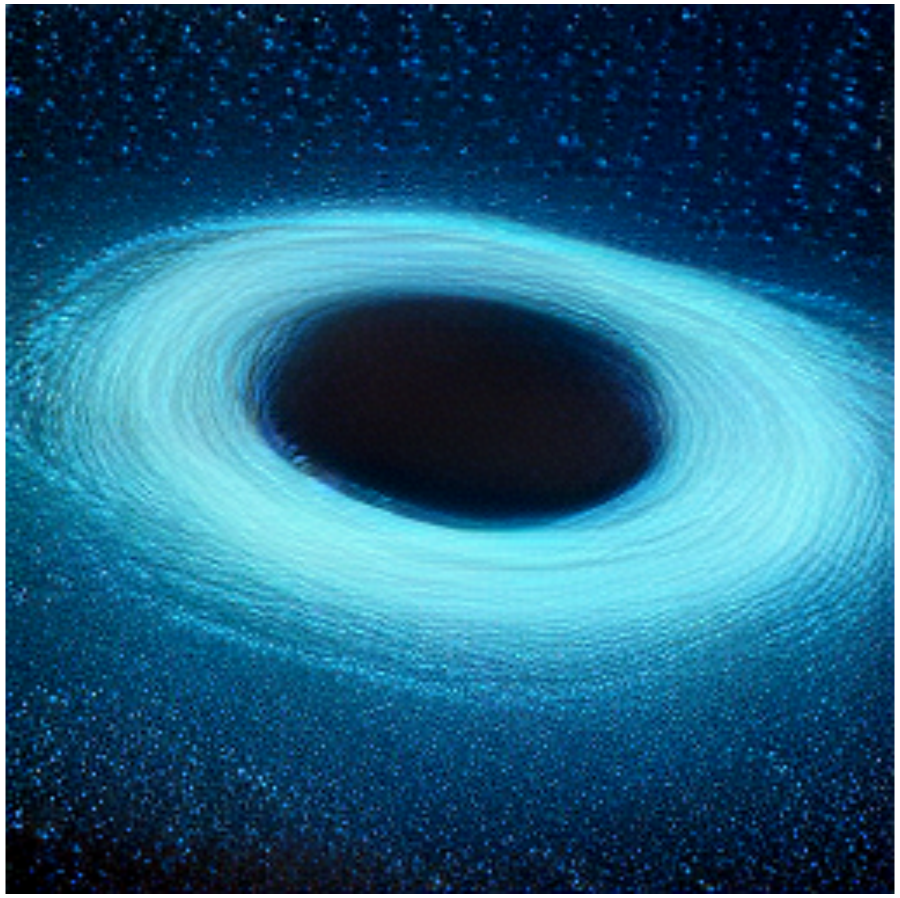
- BH is a particle detector !!
- Accreting boson star into black hole
  - Three stage
    - Stage I : Normal mode oscillation stage.
    - Stage II : Catastrophic stage
    - Stage III : Gravitational atom stage
  - accretion time scale



$$t_{\mathrm{acc}} \sim 10 \ \mathrm{Gyr} \ \mathcal{O}(1) \left(\frac{10^{10} M_\odot}{M_{\mathrm{BS},0}} \right)^5 \left(\frac{\mu}{10^{-22} \mathrm{eV}} \right)^{-6}$$

  - The time scale must be longer than Hubble time

$$\mu \lesssim 8 \times 10^{-20} \mathrm{eV}$$

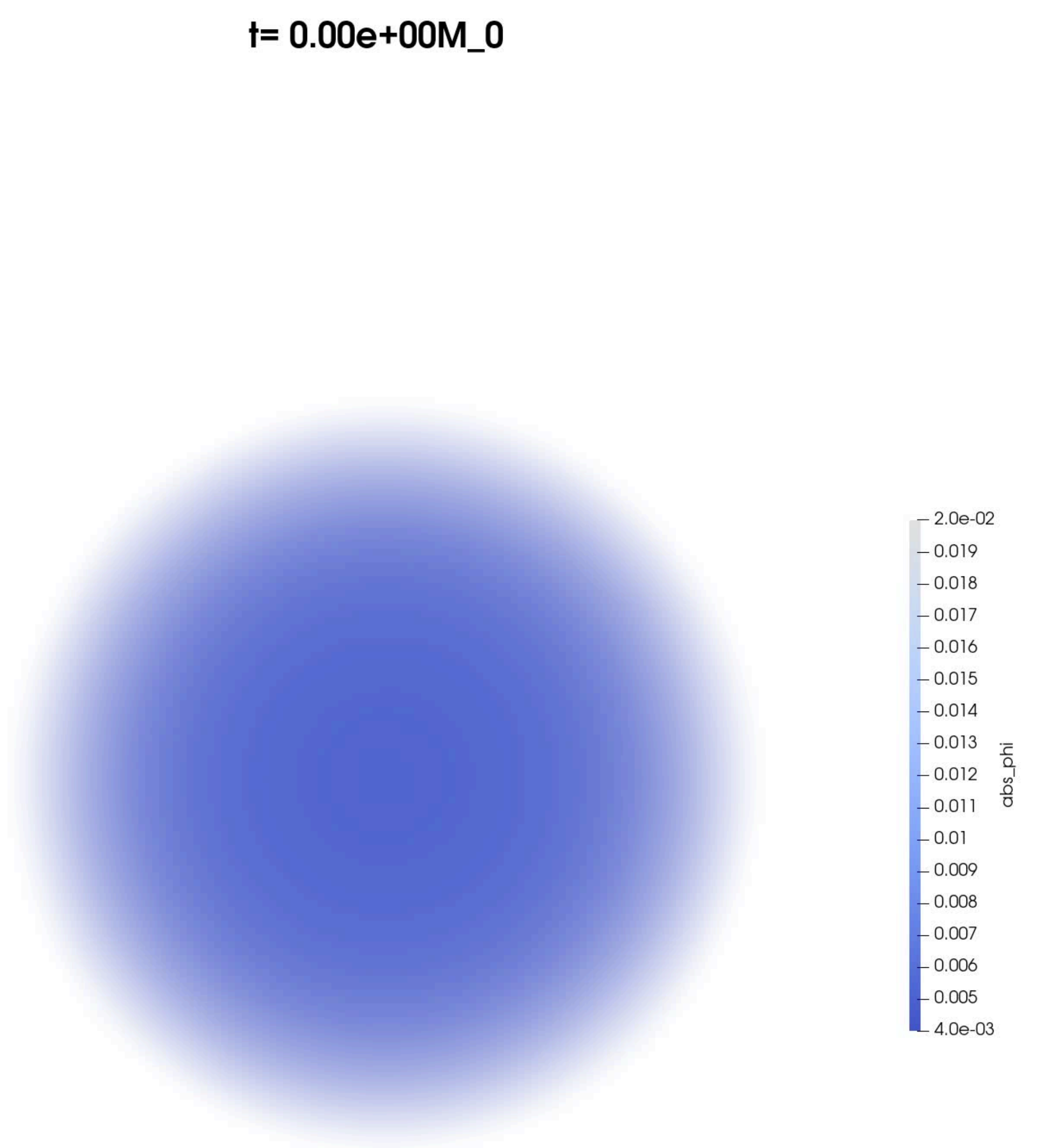


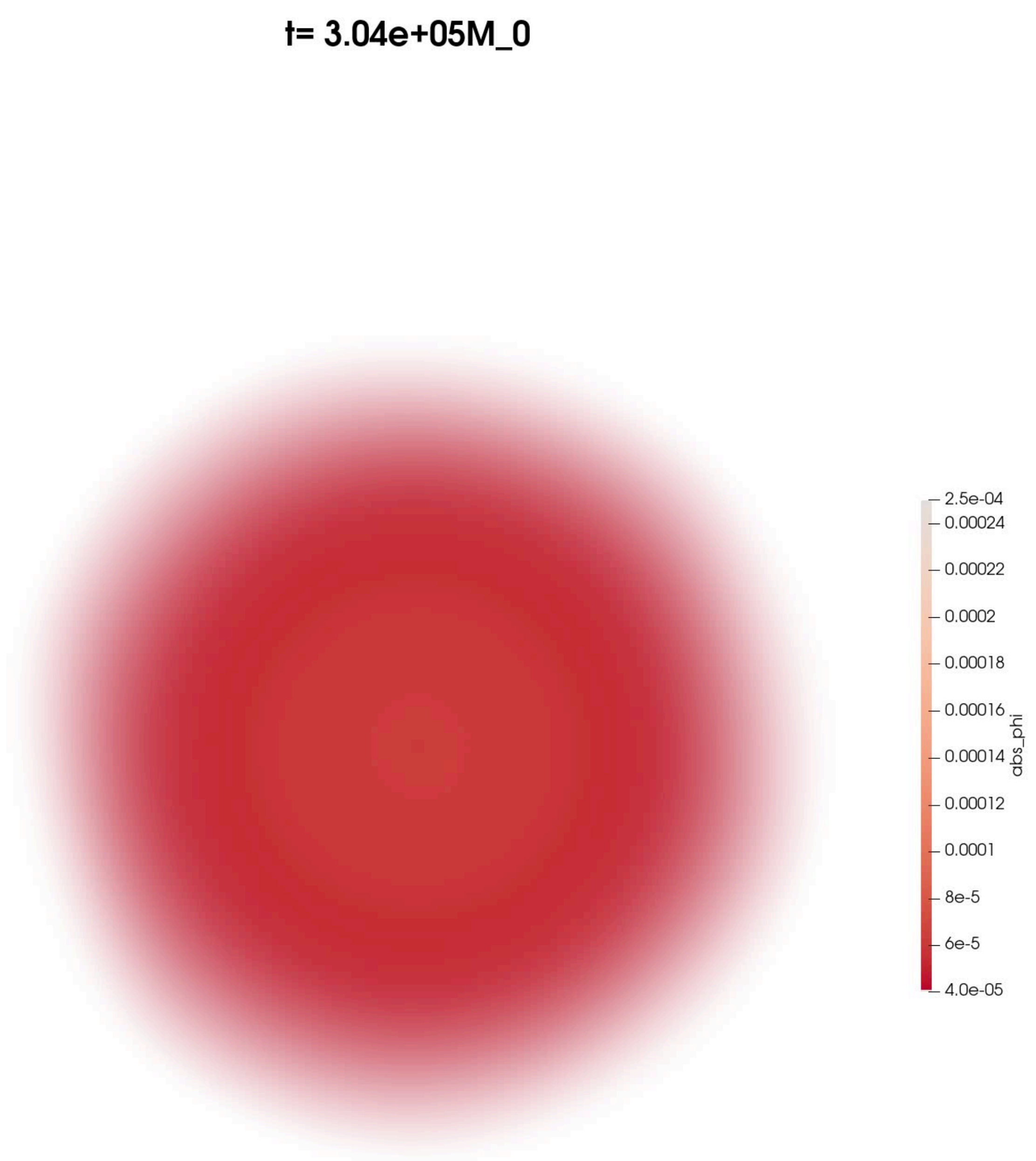
Thank you

Several comments

- If the initial configuration is not sufficiently massive, the catastrophic stage may not exit.
    - $\mu \left(M_{\mathrm{BH},0} + M_{\mathrm{BS},0} \right) \ll 0.08$
    - BH effective potential is enough to suppress accretion.
- If the initial BH mass is comparable to the BH mass, the first stage does not exit.
    - Free fall time scale : $\tau_{\mathrm{FF}} \sim \left(\frac{R_{\mathrm{BS}}^3}{M_{\mathrm{BH}} + M_{\mathrm{BS}}} \right)^{1/2}$
- Life time of boson star from first stage

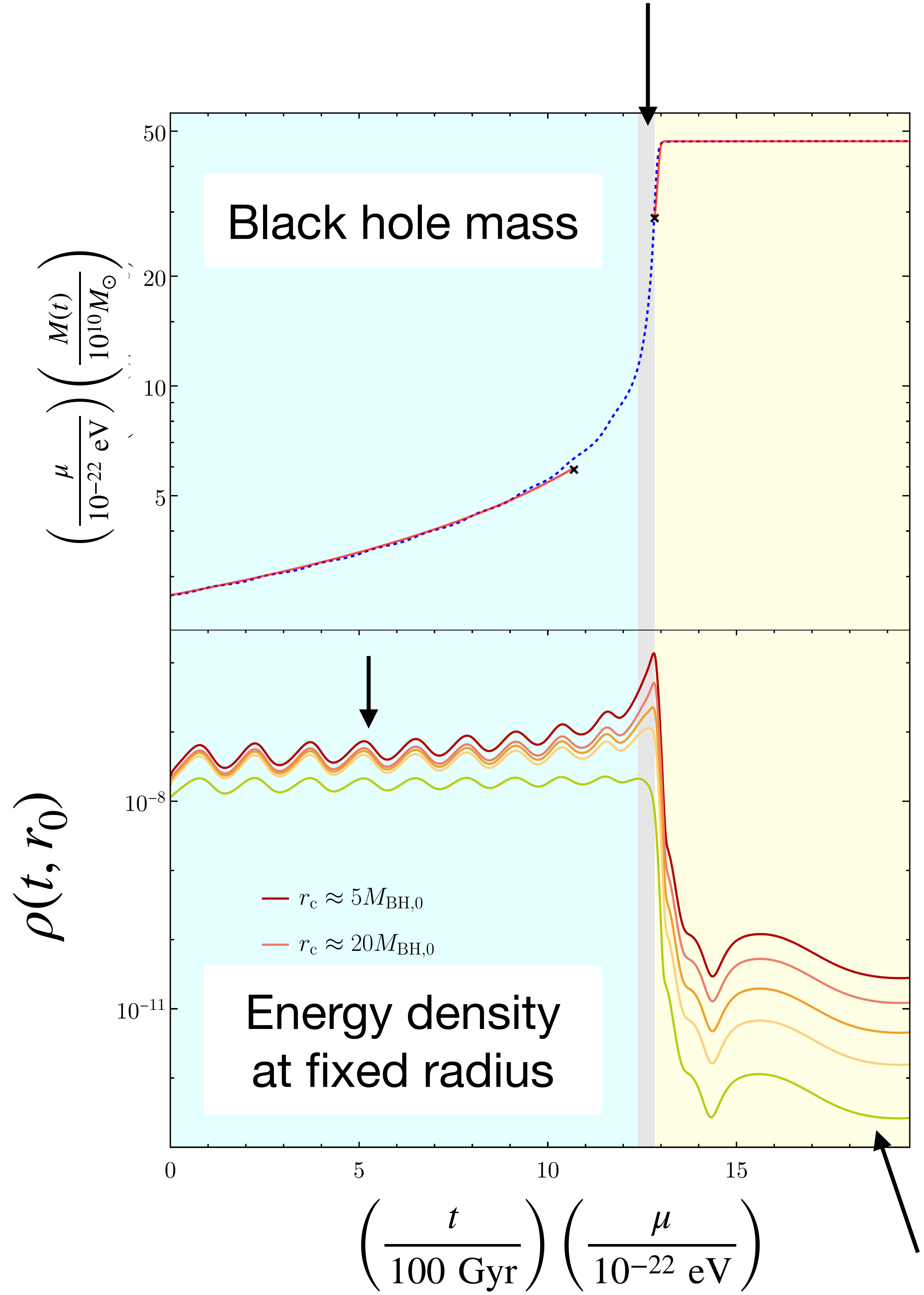
$$\frac{\tau_{10\%}}{10\ \mathrm{Gyr}} \sim \mathcal{O}(1) \left(\frac{10^{10} M_{\odot}}{M_{\mathrm{BH},0}} \right)^5 \left(\frac{\mu}{10^{-22}\mathrm{eV}} \right)^{-6}$$

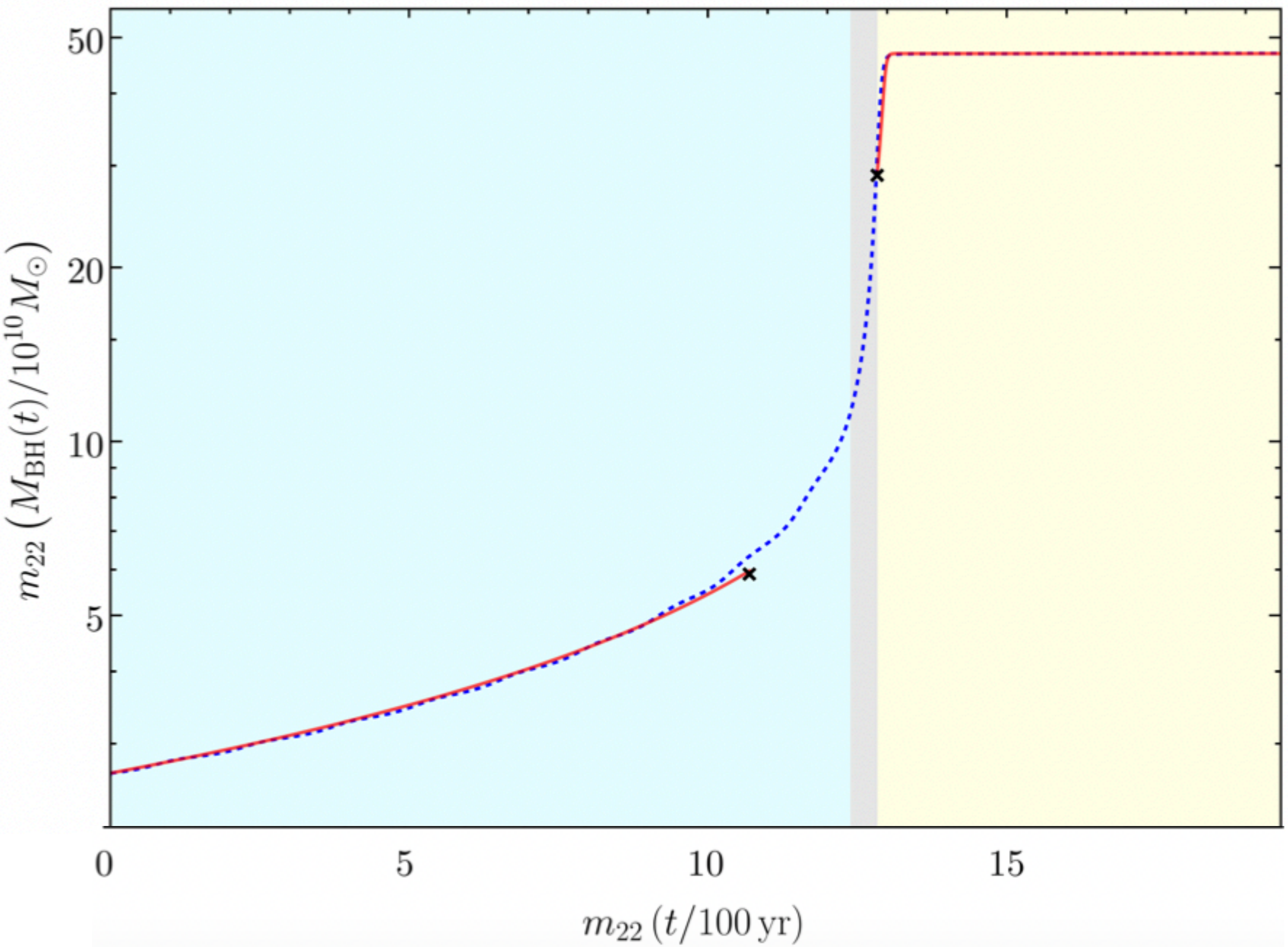

t= 0.00e+00M_0
2.0e-02
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
0.006
0.005
4.0e-03
abs_phi


t= 3.04e+05M_0
2.5e-04
0.00024
0.00022
0.0002
0.00018
0.00016
0.00014
0.00012
0.0001
8e-5
6e-5
4.0e-05
abs_phi

Numerical result

- Typical history of the accretion
  1. Normal mode oscillation phase (boson-quake)
  2. Catastrophic phase
  3. Gravitational atom phase
- Potential barrier vanishes for larger BH than $M_{\rm BH,crit} = 0.25\mu^{-1}$




50
20
10
5
0
5
10
15
$m_{22}\,(M_{\rm BH}(t)/10^{10}M_\odot)$
$m_{22}\,(t/100\,{\rm yr})$